Project Title: Soil vulnerability to future climate in the Southern Rockies Landscape Conservation Cooperative, with implications for vegetation change and water cycle

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Executive Summary

We will develop tools for managers in all watersheds of the Southern Rockies Landscape Conservation Cooperative to project the effects of climate change on soil water conditions and help them develop appropriate strategies to mitigate negative climate impacts. The overall goal of this project is (1) to develop a spatially-explicit soil vulnerability index for the Southern Rockies Landscape Conservation Cooperative that can be used to forecast the short-term response of plants to current drought conditions and test a vegetation model hindcast of plant response to drought; (2) to compare and contrast the current vulnerability index with projections of vegetation dieback under future climate change scenarios and provide some warning about areas that are still currently protected by current plant cover but where future vegetation shifts may increase soil vulnerability, thus enabling preliminary estimates of the future location of vegetation dieback and potential aeolian dust sources.

These goals address the Water Smart program tasks A.a, A.b and A.e by using downscaled climate models for the LCC's, enhancing managers' ability to look at projections of changes in precipitation levels and snowmelt rates, and projecting ecosystem responses to changes in climate and hydrology, including shifts in vegetation types and density, decreases in water availability via evapotranspiration, and changes in soil conditions. A team of soil, climate, and software experts will generate soil datasets using digital soil mapping techniques, gather state-of-the-art climate datasets to run the MC1 dynamic global vegetation model over the same spatial domain, simulate vegetation shifts, carbon gains and losses, fire risk to evaluate the spatial patterns of vulnerability for the area, test the results against local records for historical conditions, and project potential changes in soil vulnerability and available water resources. Results of this study will be made publicly accessible and usable on the web through Data Basin (www.databasin.org).

Project Description

Introduction

The recent drought (1999-2009) in the southwestern US caused rapid, regional-scale mortality of dominant pinyon pines (Pinus edulis) from infestations of bark beetles (Ips confusus) associated with extreme drought stress. This drought was more intense than the drought of the 1950s (Breshears et al. 2005) when mortality was documented on dry, often lower elevation sites, affecting older trees. The recent drought affected all age classes even at high elevations.

When the map of pinyon mortality is overlaid with a soils map of the area, soils in areas of low mortality in southwest New Mexico appear to be young, fertile Mollisols that are deeper, finer textured and richer in nutrients than soils in regions of high mortality in northern New Mexico and southern Colorado. They have a cryic temperature regime (they freeze) that allows them to store water as ice and release it when temperatures rise. Their finer texture (pore size) as well as the freeze-thaw cycles give them increased long-term water storage potential. Soils in regions of very high pinyon mortality are generally coarser with low fertility while rich in Calcium (desert caliche layers). They have a torric moisture regime (hot and dry soils) and very little horizon development. Their large pores with little capillary forces promote rapid water evaporation or drainage rather than conservation. Consequently, water and nutrients seem far more available in soils of low mortality areas. Such considerations (both climate and soil characteristics) are important for land managers interested in protecting and maintaining sustainable populations and thus valuable seed sources under warmer, drier future projected climate conditions.

Tree mortality as a result of direct or indirect impacts of climate has been included in vegetation models using various approaches. Empirical (e.g. Iverson and Prasad 2001, Hamann et al. 2006, Thuiller et al. 2008) or mechanistic (process-based) models (e.g. Schimel et al. 1997, Keane et al. 2001, Thornton et al. 2002) include species-specific parameters with temperature and soil moisture thresholds based on published empirical information on those species physiological constraints. In the case of models that use plant functional types such as dynamic global vegetation models (e.g. Bachelet et al. 2003, Scholze et al. 2006, Kucharik et al. 2006) or earth system models (ex. Ciais et al. 2008, Huntingford et al. 2008, Friedlingstein et al. 2006), a "generic" temperature or water availability threshold is defined for each functional type based on a range of values corresponding to well-known plant species assemblages that are associated with these functional types. This "average" response to climate-driven stress (heat, cold, flood, drought) can be used as a coarse scale indication of potential die-off when under certain climate conditions and given a set of soil constraints, one vegetation type gets replaced by a better adapted type. In all cases, these modeling approaches assume that soil characteristics for the area of concern have been measured and mapped appropriately and that the simulation of the hydrological cycle associated with the ecosystem is dependable.

We propose to gather and synthesize all available regional soil information to create a soil vulnerability index that captures our understanding of the region's vulnerability to climate change though its soil characteristics. We will compare hindcasts of vegetation die-offs to this index to test the model's skill at simulating the impacts of past droughts (1950s, 2000s).

We will generate improved input datasets required to run the climate change impact models and identify gaps in our knowledge base in order to focus future field sampling efforts in areas of greatest need. Using these improved soils datasets, we will simulate future vegetation die-offs using a variety of future climate scenarios and speculate on future soil vulnerability due to the change in vegetation cover.

Goals

Our goals of this project are:

1) to develop a spatially-explicit soil vulnerability index for the Southern Rockies Landscape Conservation Cooperative and compare it to records of vegetation die-off to test our understanding of areas of low water availability and potential drought stress,

2) to compare the soil vulnerability index with historical and future simulations of vegetation die-off to provide managers with some indication of how future vegetation shifts may increase soil vulnerability, particularly in areas where soils are still protected by current plant cover, thus enabling a preliminary estimate of the location of future vegetation die-offs and potential sources of aeolian dust.

> **Specific tasks:**
>
> a) expand maps of high, moderate and low sensitivity soils to cover the US portions of the LCC's (based on pH, calcium carbonate accumulations, sodium absorption ratio, wind erodibility, water erodibility, soil depth, available water capacity, hydric rating and gypsum content) including those in non-surveyed areas.
>
> b) develop a map of soils most vulnerable to changes in precipitation and temperature affecting soil water availability and storage for historical conditions and compare it to MC1 DGVM projection of vegetation response to recent droughts (1950s, 2000s).
>
> c) provide model projections over the LCC's to indicate where future vegetation shifts may influence soil conditions and mitigate or enhance soil loss.

Background

This project will benefit from on-going studies conducted as part of the BLM Rapid Ecological Assessments for the Colorado Plateau and Sonoran Desert ecoregions. The conceptual model for this project identified interconnections between soil attributes, vegetation, urban development, other human land uses, and climate change. A process-model used to identify sensitive soils (at highest risk of impact from disturbance) was developed by scientists at the BLM, USGS, NatureServe and Conservation Biology Institute to answer a set of management questions including: Where are sensitive soils in the Colorado Plateau and Sonoran Desert ecoregions? Where are soils at risk of water or wind erosion? Where are soils at risk of contributing to the dust emissions? Where are soils most vulnerable to climate change? We will take advantage of the results from this project and use the same methods (described below) to expand our spatial domain to the full extent of the Southern Rockies LCC.

Methods

1. Determining a sensitive soils index:

For every map unit (mukey), we will use a script to extract:
      1) attributes directly from the SSURGO "muaggatt" table
      2) attributes for the dominant component within the map unit from the component table. The dominant component will be determined using component with the highest representative percent (comppct_r).
      3) attributes for the horizons in all recording components. For each component, for each attribute of interest, we will average across all horizons that include non-zero values for that attribute (arithmetic average). We will then use an area-weighted algorithm to combine the components together, based on the normalized percent of each component with respect to the other components that record values for that attribute.

      Example: map unit has 3 components: A (40%), B (35%), and C (25%). For attribute of interest X, only A and C have record values. Thus we calculate re-normalized percents for A (62%) and C (38%) that are used as a multiplier to the attribute of interest.

For this study, the following SSURGO soil attributes will be extracted: Map Unit Symbol, Map Unit Name, minimum bedrock depth, available water storage at 25, 50, 100 and 150 inch depths, drainage class, hydrologic group, runoff, hydric condition, hydric rating, taxonomy, particle size, moisture regime, temperature regime, landform, saturated coefficient of conductivity, available water capacity, calcium carbonate concentration, gypsum concentration, sodium absorption ratio, pH, water and wind erodibility factors.

2. Filling data gaps:

Where SSURGO data are unavailable, surrounding information will be interpolated, using predictive soil mapping techniques (McBratney et al., 2003; Malone, 2008; Hash and Noller, 2009; Elnaggar and Noller, 2010; Peterman, 2010). Predictive soil mapping, using a regression tree analysis, using the NLCD sampling tool and See5 statistical software will be used to interpolate missing soil map units. This involves using data representing Jenny's (1941) five soil-forming factors (climate, organisms, relief, parent material and time) to develop a statistical model of environmental covariates that correspond to different soil types across the landscape. These environmental covariates will be represented by a 30 m digital elevation model, current PRISM climate data, Landfire vegetation, and state 1:100,000 geology maps for the age and lithology of the underlying bedrock. These data will be compared to the surveyed map units to determine the combinations of factors most closely related to each soil attribute of interest. Using a classification and regression tree (CART) model, a rule-set will be created and used to predict where else on the landscape similar attributes are likely to occur.

3. Soil vulnerability to climate change:

Based on soil temperature and moisture regimes, soil order, drainage class, calcium carbonate concentrations, soil particle sizes and hydrologic group, a map of low to high soil vulnerability to climate change will be created.

4. Vegetation change and future soil vulnerability:

The MC1 dynamic global vegetation (e.g. Bachelet et al. 2001) will be run for the Southern Rockies LCC domain on an 800m x 800m spatial grain to simulate 20th and 21st century vegetation distribution and shifts as well as associated water and biogeochemical (carbon, nitrogen) stocks and fluxes affecting wildfire occurrence and impacts. The model has been used for previous climate change assessments including IPCC reports and the 2000 National Assessment. It is currently used to "climatize" state and transition models used by US Forest Service staff to develop management strategies in the Pacific Northwest and Southwest regions. The MC1 vegetation model has pioneered a fully prognostic sub-model of fire and fire-vegetation interactions (Prentice et al. 2011) and has been recognized as a reliable source of fire risk estimates by Federal agencies (e.g. http://cefa.dri.edu/Assessment_Products/assess_fire_fcst.php). Uncertainty in the vegetation model results for historical conditions will be evaluated based on climate projection uncertainty, but also on a comparison between the soil information used to determine water availability and the soil vulnerability index. The full water budget will be documented and simulated streamflow compared with available USGS gage records. Areas of vegetation shifts and projected wildfires will be identified under past (tested against existing records) and future climate change using multiple GCM (Hadley, MIROC, CSIRO) and RCM (RegCLIM, WRF) projections (Tmin, Tmax, PPT, VPR) under different emission scenarios (e.g. A2), potentially identifying locations where change in plant cover might increase or decrease the potential for erosion.

As value added to this project, MC1 results can now be summarized using the ENVISION framework (Bolte et al.) where temporal and spatial averaging can occur within a user's unit of choice, currently watershed – HUC5, but also possibly by soil polygon or by topographic facet, increasing the usability and availability of the projections. Summary maps of the results will be made available through Data Basin, an on-line database that allows access, visualization, and manipulation of data freely on the web. Examples of MC1 results from past projects are already accessible through http://databasin.org/climate-center/features/mc1-dynamic-global-vegetation-model. Comparison with the soil vulnerability index maps will be facilitated through this combination of software environment.

There will be no negative environmental impacts of this study. It will be entirely conducted with existing field and remote-sensing data.

Pitfalls and limitations:

The main pitfall or limitation in this type of study is a potential lack of soils data. Most of the environmental data used in this study have national coverage, however SSURGO data can have large data gaps. Small data gaps can be effectively interpolated with predictive soil mapping, however, as the distance between surveyed data increases, the confidence in predicted data decreases. In cases where there are very large gaps in SSURGO data, STATSGO data will be used to give an indication of the soil attributes of concern in that region.

Expected outcomes

This project will provide tools to maximize the management of natural resources both affecting and affected by water resource management in a changing climate. Specific knowledge of soil conditions most likely to affect the acceptance, storage, redistribution, and quality of water is invaluable in making wise decisions about water resource management. Models are valuable tools to synthesize current information and understanding of ecosystem function. Rather than use model results as precise predictions of what the future might bring, it should enable managers to identify gaps in information and knowledge and allow them to consider environmental conditions that may not have happened in the recent past.

Results will facilitate resource management allocation. As each product is developed in keeping with the project schedule, it will be put on the web at databasin.org for review and use, and shared during webinars and organized workshops. Consequently, most products will be freely available to facilitate resource management decisions prior to project completion.

Timeline, Products and Outcomes

This is a 2-year project. Assuming a start in summer 2011, the workflow will proceed as follows:
1. Aug, 2011-Jan 2012: Integrated soil maps of all included areas at the 1:24,000 scale compiled, analyzed and updated with significant attributes.

2. Aug 2011-Jul 2012: 1) Statistical correlations of individual and combined soil characteristics and soil sensitivity based on pH, depth, wind and water erodibility, salinity, water holding capacity, wetland conditions, water holding capacity and gypsum content, 2) Initial forecast maps of high, medium and low vulnerability areas based on soil characteristics, 3) Decision-tree analysis and further predictive maps of soil vulnerability forecast, vegetation and disturbance maps.

3. Nov 2011-Nov 2012: Input dataset development, historical runs and sensitivity analysis of the MC1 DGVM model to soils input and projections of vegetation die-offs during past droughts (1950s, 2000s).

4. Mar 2011- Dec 2012: Input dataset development, gathering of state-of-the-art future climate change projections, simulation runs by MC1 DGVM model for future climate conditions and projections of vegetation die-offs.

5. Comparison and synthesis of drought impacts records, soil analyses and simulation results in peer-reviewed publication. Presentation of results at National Meetings

To communicate results, we plan to present results at three national meetings: the 97th ESA annual meeting, August 5 –10, 2012 in Portland OR, and the SSSA-ASA-CSA International Meeting, October 21-24, 2012 in Cincinnati OH, and the AGU annual meeting, December , 2012 in San Francisco, CA,.

	Aug 2011-Jan 2012	Feb-Jul 2012	Aug 2012-Jan 2013	Feb-Jul 2013
Products:				
Compile Soil maps for LCC (within USA)	XXXXXX	XX		
Predictive soil mapping of soil attributes of concern		XXXXXX	XX	X
Soil vulnerability index		XXXXXX	X	X
Sensitivity analysis of MC1		XXXXXX	XXXXXX	XX
Communication:				
Presentations at national meetings				
Interim and final reports to Reclamation; uploading in Data Basin			X X	
Manuscript preparation	X	X	X	X
				XXXXXX

Personnel and qualifications:

Wendy Peterman, Conservation Biology Institute soil scientist and GIS specialist will perform GIS analysis and soil modeling. Currently, she is developing a soil vulnerability index and tree mortality research with funding from the North Pacific LCC. She has developed sensitive soils modules for the BLM REA's for both the Colorado Plateau and Sonoran Desert ecoregions. She has been studying the connections between soil characteristics, water stress, forest mortality and climate change in the southwestern USA (manuscript submitted for publication to Geoderma), the PNW Cascades, and the California Sierras. She provided soil vulnerability index maps for Wind Cave National Park. Her method uses SSURGO, STATSGO and Forest Service remote sensing data to connect soil characteristics to forest health in a decision tree analysis to create forecast maps of where soils are more vulnerable to changes in temperature and moisture regimes as the climate changes. Peterman will also be responsible for uploading all output datasets onto databasin.org.

Dominique Bachelet has done research on global climate change issues using simulation models since 1989. She participated in the development of one of the first dynamic global vegetation models, MC1. She has gathered an extensive knowledge of the various ecosystem and dynamic global vegetation models through several model inter-comparison exercises and collaborative projects. She is currently leading several research projects with funding from federal agencies to contribute to several climate change impact assessments (Wind Cave National Park, Arizona, New Mexico, Oregon, Washington). She is also working at Conservation Biology Institute, helping develop the on-line database and data manipulation web site databasin.org to provide easy access to climate change science products, particularly climate change projections and results from impacts models, ensuring that climate change is integral to conservation planning from the outset.

David Conklin, PhD., is a climate change modeler at Conservation Biology Institute, who uses the MC1 DGVM in projecting future changes in vegetation, carbon consumed by fire, streamflow, vapor pressure, precipitation and temperature. He is currently working on incorporating MC1 data into the ENVISION framework for summarizing both model inputs and outputs data by user's sptial unit of choice e.g. watershed or soil map unit. He has over 35 years of experience as a software engineer, and has focused on climate change impacts research since 2001. He has recently produced climate change impact assessment products for the Western Wildland Environmental Threat Assessment Center (WWETAC) in the Apache-Sitgreaves study area (Arizona/New Mexico) and in eastern Oregon. His dissertation research focused on potential climate change impact on vegetation in Yosemite National Park. He has also run vegetation models for The Nature Conservancy estimating ecosystem services provided by various ecosystems across the state of California.

Ken Ferschweiler works as a software engineer and modeler at Conservation Biology Institute, improving and running the MC1 vegetation model. He has 30 years of experience in developing computing applications, and nearly ten years of experience in working with scientists to help them more effectively use computers. His work has focused especially on the use of high-performance and parallel computing, and, more recently, cloud computing. In previous positions, Ferschweiler led a team that developed software for the NSF-funded Network for Earthquake Engineering Simulation, a nationwide distributed research collaboratory, and led another team that developed a system for management of high-performance computing data for the US Dept. of Defense. He has worked with climate scientists at NASA to help them improve performance, workflows, and user interfaces in use of supercomputing resources, and developed software to provide scientists and other academics with tools to support web exploration of large scientific databases.

Brendan Ward, software engineer, will provide technical support in tool development and online publishing throughout the two-year project. Since 2007, he has been contributing heavily to the Data Basin project (www.databasin.org). He has been highly involved with data acquisition, processing, and loading into the system, which has included writing many custom geoprocessing tools to prepare data. He is also the lead software architect and engineer for Data Basin, coordinating a team of software developers to build, enhance, and manage this system. As such, he has been heavily involved in java, javascript, html, css, and python software development. He has also developed core functionality on the ArcGIS server platform, including custom server extensions and geoprocessing tools as required to support Data Basin. In addition, he has developed custom geoprocessing tools for client projects, including tools to extract soils information from SSURGO, summarize many landscape variables at the watershed level, and perform various other analyses.

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